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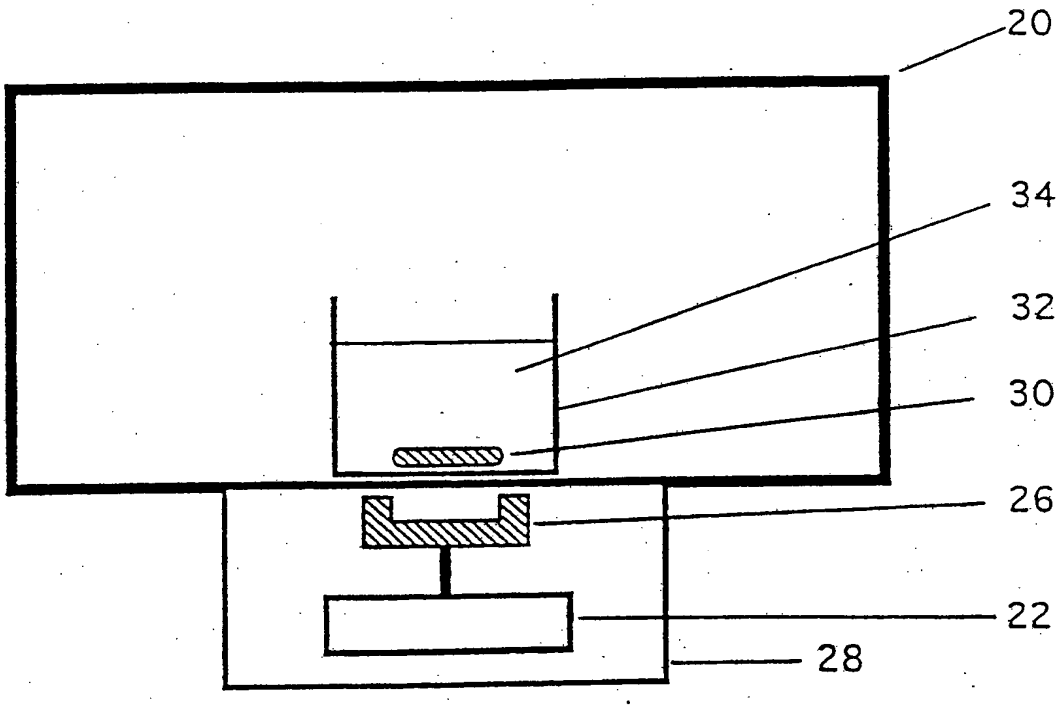

(57) Abstract

A method and apparatus is provided for stirring a fluid (34) while irradiating the fluid with microwave or radio frequency radiation. The apparatus includes a stirring element (30) containing magnetised material which is driven by magnetic coupling between it and a rotating or oscillating magnetic field (22-24-26) which is produced either within or outside the confines of the microwave or radio frequency field.

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MIXING DURING MICROWAVE OR RF HEATING

Technical Field

This invention is concerned with the agitation of a fluid medium while in a microwave or radio frequency (RF) electromagnetic field to minimize temperature gradients and to ensure uniform distribution of suspended components (if any) of the fluid while it is undergoing microwave or radio frequency heating.

Background Art

Exposing a fluid to microwave or RF radiation is a quick and convenient method of heating it provided the fluid or a material in contact with the fluid absorbs microwave or RF radiation. This form of heating is useful both industrially and domestically for promoting chemical or physical changes, for example, the cooking of food. However in unagitated batch systems which heat the fluid in a container the temperatures vary greatly from place to place in the contained fluid. This effect has at least two causes: first, the microwave or RF radiation field is not uniform in space or time, second the radiation intensity in an absorbing fluid decays with depth - typically with an aqueous fluid in a 600W domestic type microwave oven the bulk of the energy is deposited in the first 1-2 cm. Equipment modifications to cope with the problem of non-uniformity of field strength include means for rotating the container upon a turntable or using a rotating mode stirrer fan at the point where the microwave radiation is introduced to the heating chamber; both methods average the field strength at a point in the fluid being heated to produce apparent uniformity. Recent domestic microwave equipment has used both approaches simultaneously.

The limited depth of radiation penetration and consequently of heating effect is more difficult to overcome. The usual solution in food cookery is to interrupt the irradiation process one or more times during the heating cycle, remove the container of fluid and mechanically stir the fluid until it is uniform. This is particularly necessary where the heating produces a significant change in the viscosity of the fluid eg the denaturation of proteins or starch, the gelation of plasticised vinyl polymers. In the reheating of frozen foods obtaining a uniform temperature throughout the food mass is important to obtain complete sterilization while avoiding deterioration of some parts of the food mass due to overheating.

The interruption of heating to allow mixing is at best inconvenient and at worst dangerous due to the risk of evaporation of volatile constituents from the hot fluid; the latter is of particular concern if the microwave or RF heating is being used to promote chemical reactions, involving toxic or flammable materials. There have been many attempts at devising apparatus for agitating fluids while in a microwave or RF field and generally these have not been particularly convenient or practical.

These prior art methods generally comprise mechanical arrangements wherein relative motion between the fluid in a container and a stirrer is produced by generally fixedly mounting the stirrer and rotating a container containing the fluid, with all of the componentry being within the microwave or radio frequency field. Examples of this prior art are given in British patent application GB-A-2,230,409, European application EP-A-312373, South African ZA-A-8704314 and Great Britain application No. GB-A-2,159,027. Another approach has been to use a

separately powered rotating stirrer immersed in the fluid - United States patent No. 4,959,517 is an example.

The above prior art arrangements are complicated and cumbersome. Further they cannot be easily removed from the heating chamber and thus take up much room. Some mechanisms require apertures in the walls of the microwave or radio frequency cavity which may allow leakage of radiation and none offers a convenient method of stirring in a closed pressurized vessel as may be required in certain industrial applications.

Magnetic stirring is a known method of agitating liquids and is widely used in scientific laboratories. It commonly uses an electric motor to rotate a magnet located below the vessel to be stirred. A bar magnet residing in the stirring vessel containing the liquid is caused to rotate by the rotating magnetic field produced by the mechanically rotated magnet. However, as far as the applicants are aware, this form of stirring has not been used within a magnetic or radio frequency field because of an expectation that the magnetic or magnetisable material would interact with the magnetic field component of the microwave or RF radiation and thus absorb energy and produce heat. For example, the absorption of microwave energy by paramagnetic and ferromagnetic materials has been exploited in the processes described by US Patent Nos. 4,345,983 and 4,545,879, which patents describe chemical processes in which magnetic materials absorb microwave or radio frequency energy and produce sufficient heat to cause high temperature chemical reactions to occur between chemicals that are adsorbed on the surface of the magnetic material. It would not therefore be expected that a magnet could be irradiated with microwaves without generating heat.

Surprisingly however, and contrary to expectations, the applicants have discovered that a stirring element containing a magnetic or magnetisable material when immersed in a fluid in a moving magnetic field can be successfully used as a method of stirring to minimize temperature gradients in the fluid and maintain uniformity of the fluid during microwave or radio frequency irradiation.

Disclosure of the Invention

In a first aspect the invention provides a method for stirring fluids while irradiating the fluid with microwave or radio frequency (RF) radiation comprising:

i) locating a stirring element, which contains a magnetisable material, within the fluid,

ii) producing a rotating or oscillating magnetic field and causing the field to interact with the stirring element so that a corresponding rotational or oscillatory movement of the stirring element is produced, thereby stirring the fluid, and

iii) applying a microwave or radio frequency electromagnetic field to the fluid and stirring element.

In a second aspect the invention provides an apparatus for stirring a fluid while irradiating the fluid with microwave or radio frequency (RF) radiation comprising a stirring element for immersion in the fluid, the material composition or structure of the element being such that it interacts with an applied rotating or oscillating magnetic field so as to be moveable therewith, first means for applying a rotating or oscillating magnetic field to the

stirring element while the element is within a fluid within a microwave or radio frequency electromagnetic field and second means for generating the microwave or radio frequency electromagnetic field.

According to the invention the applicants have shown that magnetic agitation is an applicable technique in microwave or radio frequency heating chambers. The attractive features of this technique are its simplicity and its convenience.

With the invention there need not be cumbersome drive shafts taking up room in the chamber, nor need there be any apertures which might allow leakage of radiation. The latter is an important point when meeting safety standards. Furthermore magnetically energised agitation requires no special vessels for containing the fluid and a variety of shapes and sizes of stirring element may be employed. Another advantage is that in some industrial applications, such as chemical processing, the stirring element can be employed in a closed pressurized vessel without leakage. The invention may be employed in a domestic or commercial situation using a stirring element of suitable shape coated with an inert non-toxic material for cooking or preparing soups, stews and other fluid foods which require heating.

The invention is particularly useful in applications involving the batch processing of fluids, for example the heating of foodstuffs or chemical reagents in microwave ovens, wherein it minimizes temperature gradients within the fluid and maintains uniformity of distribution of suspended components (if any). Thus the stirring element of the apparatus according to the invention may be placed within a fluid which is suitably contained in a region to which the microwave or radio frequency radiation is

applied, and the means to apply the moveable magnetic field is placed in proximity to the container so as to cause movement of the element thereby stirring or agitating the fluid.

The stirring element may comprise magnetisable material or a magnet encased in a non-corrodible material designed to avoid contamination of the fluid being mixed. This noncorrodible material may be plastics, glass, ceramic, or inert metal in any suitable shape to give good mixing when the element moves in response to the moving magnetic field. The magnetisable material may be any suitable ferromagnetic or paramagnetic material that is of any suitable shape to interact with the moveable magnetic field. Suitable ferromagnetic metals are, for example, iron, cobalt, nickel or their alloys.

The stirring element may contain a ferromagnetic material which is a good conductor or which is coated with a thin layer of a good conductor, for example silver, which may be applied by electroplating. With this construction use is made of the "skin effect" to minimise absorption of the microwave or radio frequency radiation by the element.

The moveable magnetic field may be generated in any convenient way, the most simple being by means of a permanent magnet attached transversely to the shaft of a drive motor which is placed outside the heating chamber underneath the location of the container of fluid being heated; rotation of the motor causes the generation of a rotating magnetic field inside the container.

Alternatively a drive mechanism for connection to the turntable drive in a domestic type microwave oven could be provided to rotate a magnet. This results in the rotating

or oscillating magnetic field being generated within the heating chamber.

Alternatively the moveable magnetic field may be generated by means of appropriately located coils carrying an electric current. The magnetic field source may be located inside or outside the heating chamber.

Persons skilled in the art will appreciate that the magnetic coupling between the rotating or oscillating magnetic field and stirring element depends on the strength of the field, the material, dimensions or magnetic properties of the magnetisable material and the proximity of the element to the field. Preferably the stirring element includes a magnet. Factors determining the strength of the magnetic coupling may be varied as may be required for a particular application. For example, a stronger magnetic coupling will be required for stirring a viscous fluid in contrast to that for a fluid of lower viscosity, such as an aqueous fluid.

Brief Description of Figures

Embodiments of the invention will now be described with reference to the accompanying Figures wherein -

Figure 1 schematically illustrates one embodiment of the invention;

Figures 2 (a), (b) and (c) illustrate examples of stirring elements.

Best and Other Modes for Carrying Out the Invention

In the example of the invention as shown in Figure 1, reference 20 indicates the heating chamber or cavity of,

for example, a domestic microwave oven. Mounted beneath the base of the cavity 20 is a drive motor 22 having a shaft 24 upon which is mounted a magnet 26; the motor, shaft and magnet being enclosed in housing 28. Operation of the motor causes the magnet 26 to rotate to produce a rotating magnetic field to interact with a magnetic or magnetisable stirring element 30 within the cavity 20, thereby also rotating the stirring element. The stirring element 30 is shown within a container 32 containing a fluid 34 to be stirred whilst undergoing heating. The stirring element preferably comprises a bar magnet encased in Teflon polymer.

Examples of stirring elements are shown in Figures 2(a), (b) and (c). In each figure, the stirring element includes a magnet 40 encased within a suitable plastics material 42, 44 or 46 to provide the shapes as are illustrated. Obviously, other shapes as may be desired could be provided.

The operation of this invention is demonstrated by the following non-limiting examples.

Example 1

The following experiment establishes the efficiency of the stirring and the minimization of temperature gradients achieved by use of this invention. A magnetic stirrer system was fitted to a domestic microwave or radio frequency oven as depicted in Figure 1. A 100 ml Pyrex beaker containing 80 mls of water was placed in the center of the microwave or radio frequency cavity, the depth of the water was 44 mm. Two fibre optic temperature probes were placed in the water: one measured the temperature at a point 10 mm below the surface and the other at a point 1 mm above the bottom of the beaker. Heating

experiments were conducted, with and without the magnetic stirrer, at the same power setting over the same time duration.

In the first experiment the initial temperature was measured as 22°C at both measurement points. After heating without stirring, the temperatures at the two measurement points increased to 85°C and 68°C respectively. The higher temperature was recorded just below the surface as would be expected with a microwave or radio frequency source located above the fluid being heated. Thus, after two minutes, a temperature difference of 17°C had developed.

The second experiment was conducted with stirring according to this invention. The initial temperature was recorded as 19°C at both measurement points. During the two minute period of heating, the recorded temperature difference never exceeded 1°C. In fact, for most of the time the temperature difference was less than 0.5°C. The final temperature was measured as 95°C by both sensors.

By plotting the recorded temperatures against time, it was shown that the temperature increase was linear in both experiments.

Example 2

The following experiment establishes the efficiency of the stirring achieved by use of this invention when a large increase in viscosity occurs as a result of the heating. The apparatus of Example 1 was used to make custard in the following manner. Commercial custard powder (30g) was blended by hand with cold water (250ml). After addition of a Teflon coated bar magnet the beaker of blend was placed in the centre of the microwave chamber over the

magnetic stirrer. The mixture was heated for five minutes at 600W microwave power while being stirred continuously after which time the custard had thickened. The final product was smooth and uniform with very high viscosity.

The temperatures measured during heating were:

Time (min)	Temperature °C
0	21
1	37
2	51
3	64
4	76 (started to thicken)
5	86 (very thick)

Those skilled in the art will appreciate that the invention described herein is susceptible to variations and modifications other than those specifically described and it is to be understood that the invention includes all such variations and modifications which fall within its spirit and scope.

C L A I M S

1. A method for stirring a fluid while irradiating the fluid with microwave or radio frequency (RF) radiation comprising:

i) locating a stirring element, which contains a magnetisable material, within the fluid,

ii) producing a rotating or oscillating magnetic field and causing the field to interact with the stirring element so that a corresponding rotational or oscillatory movement of the stirring element is produced, thereby stirring the fluid, and

iii) applying a microwave or radio frequency electromagnetic field to the fluid and stirring element.

2. A method as claimed in claim 1 wherein the fluid and stirring element are placed in a container and the container is then positioned within a microwave or radio frequency heating chamber.

3. A method as claimed in claim 2 wherein the container is positioned so that the stirring element will interact with a rotating or oscillating field produced by a means located outside the chamber.

4. A method as claimed in claim 2 wherein the container is positioned so that the stirring element will interact with a rotating or oscillating field produced by a means located within the chamber.

5. Apparatus for stirring a fluid while irradiating the fluid with microwave or radio frequency (RF)

radiation comprising a stirring element for immersion in the fluid, the material composition or structure of the element being such that it interacts with an applied rotating or oscillating magnetic field so as to be moveable therewith, first means for applying a rotating or oscillating magnetic field to the stirring element while the element is within a fluid within a microwave or radio frequency electromagnetic field and second means for generating the microwave or radio frequency electromagnetic field.

6. Apparatus as claimed in claim 5 wherein the stirring element includes a magnetisable material.

7. Apparatus as claimed in claim 6 wherein the stirring element includes a magnetisable and electrically conductive metal.

8. Apparatus as claimed in claim 5 wherein the stirring element includes a bar magnet.

9. Apparatus as claimed in claim 5 wherein the stirring element is coated with a non-corrodible material to avoid contaminating the fluid being mixed.

10. Apparatus as claimed in claim 9 wherein the non-corrodible material is selected from the group comprising plastics, glass, ceramic and inert metal.

11. Apparatus as claimed in claim 5 wherein the stirring element has an elongate shape to facilitate its interaction with an applied magnetic field and the stirring of a fluid.

12. Apparatus as claimed in claim 7 wherein the metal is selected from the group comprising iron, cobalt,

nickel and alloys containing any one or more of these elements.

13. Apparatus as claimed in claim 5 wherein the confines of the microwave or radio frequency field are defined by a chamber.

14. Apparatus as claimed in claim 13 wherein the means for applying a rotating or oscillating magnetic field is located outside the chamber.

15. Apparatus as claimed in claim 13 wherein the means for applying a rotating or oscillating magnetic field is located within the chamber.

16. Apparatus as claimed in claim 14 wherein the means for applying the magnetic field comprises a permanent bar magnet attached transversely to the shaft of a drive motor.

17. Apparatus as claimed in claim 13 wherein the chamber is that of a domestic microwave oven.

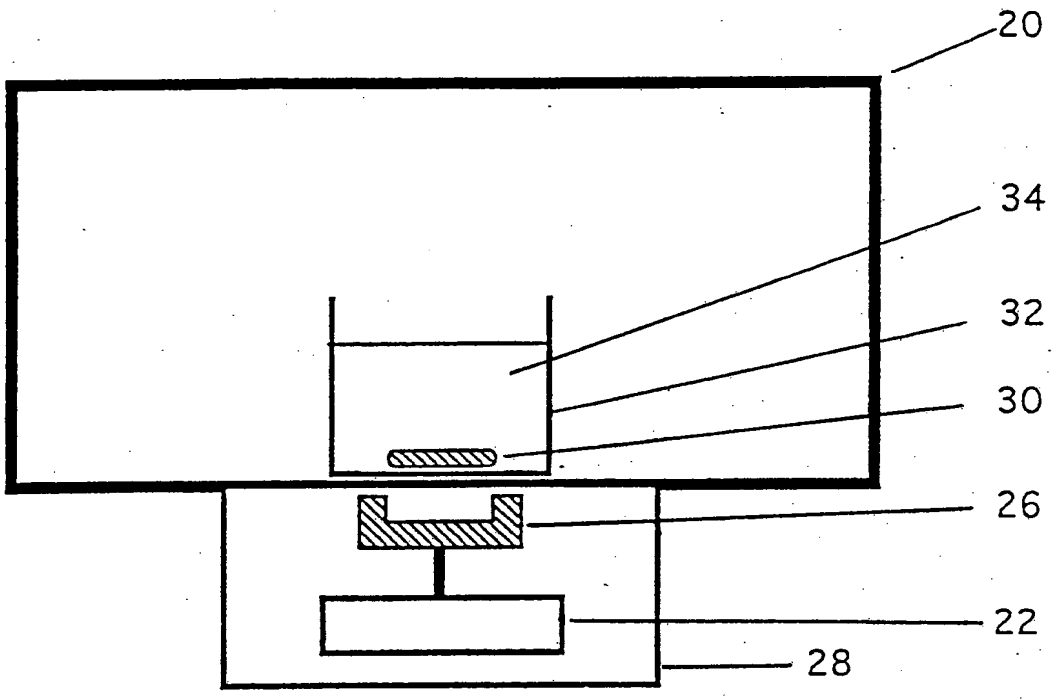

FIG. 1

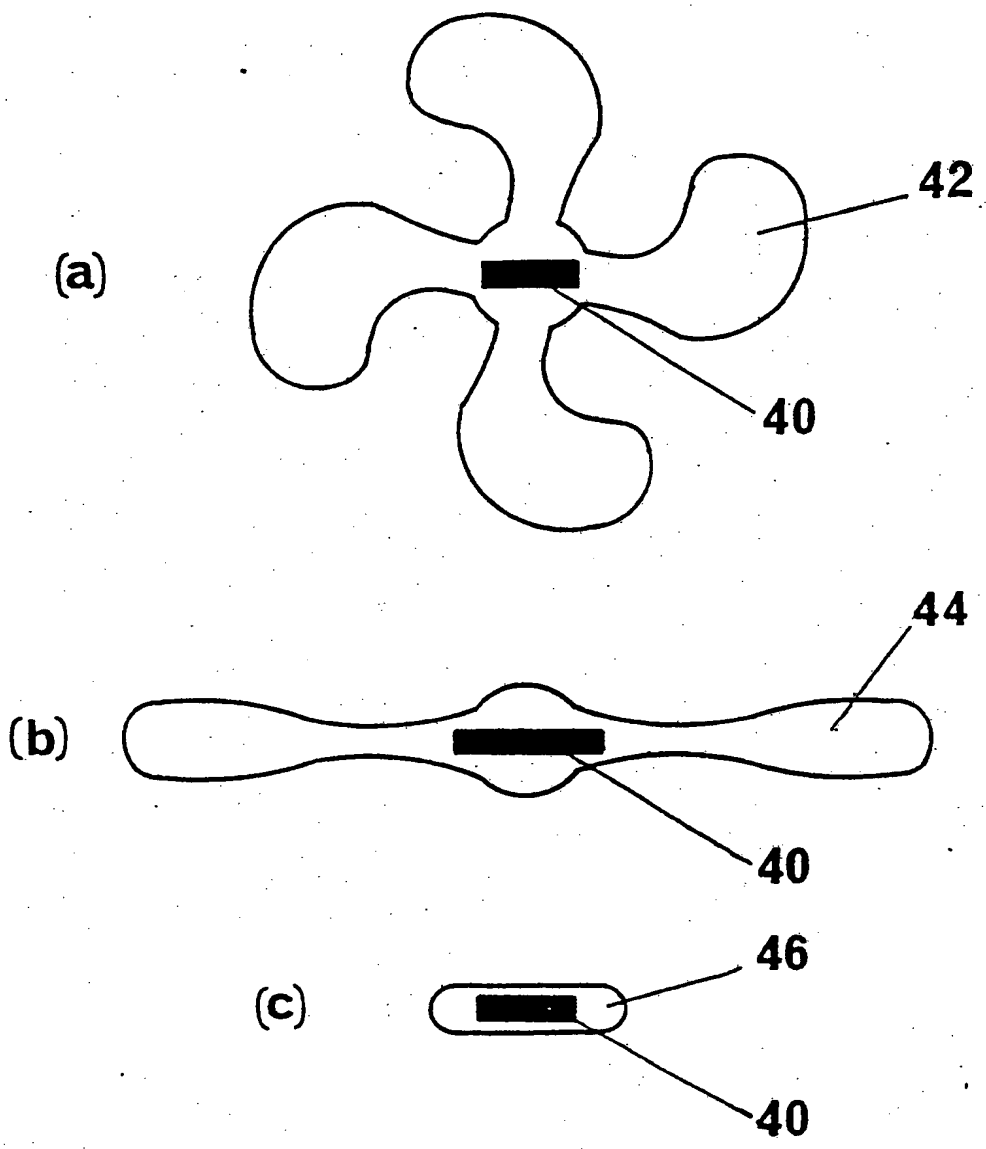

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU92/00454

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl.[5] F24C 7/02, H05B 6/78

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC : F24C 7/02 with keyword "magnet", H05B 6/78, 9/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU : IPC as above

Electronic data base consulted during the international search (name of data base, and where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	Patent Abstracts of Japan, M-77, page 6391, JP,A, 52-115450 (MATSUSHITA DENKI SANGYO KK) 28 September 1977 (28.09.77)	1-3,5-6,13-14,16-17
Y		4,7-12,15
A	US,A, 4167661 (OHKUBO) 11 September 1979 (11.09.79)	
A	US,A, 4845327 (IWABUCHI et al) 4 July 1989 (04.07.89)	
A	US,A, 4742202 (CAMPBELL et al) 3 May 1988 (03.05.88)	
A	US,A, 4980529 (BOLTON) 25 December 1990 (25.12.90)	

[X] Further documents are listed in the continuation of Box C.

[ ] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
11 November 1992 (11.11.92)	4 Dec 1992 (04.12.92)
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200 WODEN ACT 2606 AUSTRALIA Facsimile No. 06 2853929	Authorized officer R.G. TOLHURST Telephone No. (06) 2832187

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate of the relevant passages	Relevant to Claim No.
A	US,A, 4959517 (JUMP et al) 25 September 1990 (25.09.90)	
A	DE,A, 3930337 (SCHULZE) 4 March 1991 (14.03.91)	

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
US	4167661	CA	1083677	JP	52101744